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ORIGINAL RESEARCH

THE RELATIONSHIP BETWEEN ISOTONIC PLANTAR FLEXOR ENDURANCE, NAVICULAR DROP, AND EXERCISE-RELATED LEG PAIN IN A COHORT OF COLLEGIATE CROSS-COUNTRY RUNNERS

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ABSTRACT

Purpose: The purpose of this study was to examine the relationships between isotonic ankle plantar flexor endurance (PFE), foot pronation as measured by navicular drop, and exercise-related leg pain (ERLP).

Background: Exercise-related leg pain is a common occurrence in competitive and recreational runners. The identification of factors contributing to the development of ERLP may help guide methods for the prevention and management of overuse injuries.

Methods: Seventy-seven (44 males, 33 females) competitive runners from five collegiate cross-country (XC) teams consented to participate in the study. Isotonic ankle PFE and foot pronation were measured using the standing heel-rise and navicular drop (ND) tests, respectively. Demographic information, anthropometric measurements, and ERLP history were also recorded. Subjects were then prospectively tracked for occurrence of ERLP during the 2009 intercollegiate cross-country season. Multivariate logistic regression analysis was used to examine the relationships between isotonic ankle joint PFE and ND and the occurrence of ERLP.

Results: While no significant differences were identified for isotonic ankle PFE between groups of collegiate XC runners with and without ERLP, runners with a ND >10 mm were almost 7 times (OR = 6.6, 95% CI = 1.2-38.0) more likely to incur medial ERLP than runners with ND ≤ 10 mm. Runners with a history of ERLP in the month previous to the start of the XC season were 12 times (OR = 12.3, 95% CI = 3.1-48.9) more likely to develop an in-season occurrence of ERLP.

Conclusion: While PFE did not appear to be a risk factor in the development of ERLP in this group of collegiate XC runners, those with a ND greater than 10 mm may be at greater odds of incurring medial ERLP.

Level of Evidence 2b.

Key Words: exercise related leg pain, medial tibial stress syndrome, running, shin splints

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INTRODUCTION

A 2008 National Sporting Goods Association (NSGA)[1] study estimated from a sample of 10,000 households that 35.9 million people participate in running/jogging more than five times a year. This estimate was an 18.2% increase from the 2007 estimates for running/jogging participants aged 7 years or older. Running USA reported that an estimated 507,000 runners finished a marathon in 2010, an 8.6% increase from 2009 and a 255% increase from 1980.[2] Women are largely responsible for the growth in marathon running, comprising 41% of participants in 2010, as compared to 10% participation in 1980. Growth in running participation has also led to an increased interest in running related injuries. Authors who have studied the incidence of overuse leg injuries in runners report injuries occurring between 14.6% and 38.8% of the subjects.[3-8] Researchers who have examined overuse leg injuries in collegiate cross-country runners have reported incidence estimates of such injuries occurring in 26.3% and 38.8% of athletes.[4,5,8] In a survey of 844 recreational runners, the proportion of injuries to the lower leg was second only to the knee, with tibial stress syndrome being the most commonly diagnosed injury overall.[9]

Exercise-related leg pain (ERLP) and shin splints are non-specific terms used to describe lower leg injuries resulting from cumulative, microtraumatic events.[3-8,10-28] ERLP is described as a regional complex of injuries causing "pain in the anterior, medial, posterior, or lateral leg associated with exercise."[5] Burne et al[3] further distinguished the location of ERLP by excluding subjects with anterior, posterior and lateral leg pain in their study on exertional medial tibial pain (EMTP). Common medical diagnoses associated with ERLP include tendinopathy, stress fracture, medial tibial stress syndrome (MTSS), chronic exertional compartment syndrome, periostitis, nerve entrapment, and vascular insufficiency.[15,28-31]

Risk factors for overuse injuries are often classified as intrinsic or extrinsic, and modifiable or non-modifiable. Intrinsic risk factors are characteristics such as age, gender, and injury history while extrinsic factors include training surface, training volume, and equipment.[28,32,33] Modifiable factors include strength, flexibility and training variables that can be altered with direct intervention, while non-modifiable factors include age and gender. Meeuwisse et al[32] proposed a model emphasizing the interaction of both internal and external factors in creating a situation of susceptibility for the athlete, with injury occurring in the presence of an inciting event or events. This model also reflects how exposure to inciting events can result in adaptation of modifiable traits, resulting in an increased or decreased risk of injury. Prevention of injury occurs by addressing modifiable traits such as strength, flexibility, and balance through exercise or minimizing exposure to inciting events.[32] Research examining risk factors for sports injury should focus on modifiable factors that can be reliably measured.[34]

Excessive pronation has been frequently studied as a potential risk factor in the development of leg injuries in runners.[4-8,11,12,14,24,25,27,35] Previous studies using navicular drop (ND) as a measure of pronation have reported significant relationships to ERLP[8] and MTSS.[12,14] Other studies did not find a significant relationship between ND and medial leg pain creating a knowledge-knowledge conflict.[4,5,11,24] Modifying pronation with exercise and orthotic prescription is often included in the management of overuse lower extremity injuries. Pronation as measured by two-dimensional video analysis has been shown to decrease during treadmill running following eight weeks of isokinetic inversion and eversion strength training.[36] Foot orthotics have been shown to alter rearfoot motion - a component of pronation – supporting their use in decreasing the demand on soft tissue structures and reducing injury.[37,38]

The inability of the leg muscles to attenuate ground reaction forces has been suggested as a possible mechanism leading to ERLP.[3,20,39] Madeley et al[20] examined the isotonic endurance of ankle plantar flexors (PFE) in 30 athletes with MTSS and 30 matched controls. They found a significant difference in ankle PFE in the MTSS group when compared to the matched controls. As a retrospective, case-control study was used, a temporal relationship between PFE and MTSS could not be established, but their results warrant further investigation.

Successful prevention of sports injuries requires the prompt and empirical treatment of identifiable and modifiable risk factors.[32] Understanding the relationship between ankle PFE, pronation and the development of ERLP may assist in the prevention and treatment of injury in runners. The purpose of this study was to measure isotonic ankle PFE and pronation, and then prospectively determine their relationship to in-season occurrence of ERLP in collegiate cross-country runners. Gender, height, weight, body mass index (BMI), orthotic use, and previous injury were also recorded as prior studies have reported that these factors have a significant influence on injury occurrence.[7,14,24,40,41] The authors expected that decreased PFE or increased pronation would increase the risk of developing ERLP among a cohort of collegiate cross-country runners during an intercollegiate XC season.

METHODS

Subjects and Setting

This study used a prospective, cohort design. An a priori power analysis was performed using an alpha level of 0.05, a power of 0.80, an estimate of 40% of subjects exposed to navicular drop > 10 mm, and a relative risk of 2.0. It was estimated that a sample size of 262 subjects was needed to detect a statistically significant association between ND and ERLP.

Seven collegiate institutions with an estimated total of 150 cross-country athletes were invited to participate in this study. Subjects from four universities in Missouri and one college in Illinois were recruited prior to the 2009 cross-country season. An initial meeting was scheduled with coaches and athletes at each institution to describe the study's purpose and design and obtain informed consent. Researchers then met with those subjects consenting to participate to describe the measurement process and commence data collection. To be included in the study, subjects had to be free of injury at the beginning of the fall season, as defined by the ability to participate fully in team-prescribed practice and competitive activities. Subjects were excluded based on a surgical history related to the lower extremity, or if the runner was unable to participate fully in running activities due to injury. The final study cohort consisted of 44 male and 33 female collegiate cross-country runners. The study was approved by the Rocky Mountain University of Health Professions Institutional Review Board and the Saint Louis University Institutional Review Board.

Data Collection

Anthropometric Measures

Baseline anthropometrics were measured for each subject; height was measured using a cloth tape adhered to a wall and weight was measured using an electronic scale. Body mass index (BMI) was calculated using the height and weight measure for each subject.

Navicular drop

Navicular drop (ND), defined as the difference between the height of the navicular tuberosity in subtalar joint neutral and the height of the navicular tuberosity in relaxed stance, was measured bilaterally as described by Brody[42] and has been considered a reliable (ICC = 0.78-0.83) and valid measure of foot pronation.[43,44] With the subject standing barefoot, the navicular tuberosities were palpated and marked with a felt-tipped pen. Subjects were then asked to stand on the leg being tested with the opposite knee flexed and the hip maintained in neutral. The examiner palpated the medial and lateral prominence of the talus with the thumb and index finger during pronation and supination of the foot. The examiner placed their opposite hand on the lower leg to cue the subject and guide internal and external lower leg rotation. Subtalar joint neutral (STJN) was determined when the talar prominences were congruent medially and laterally. The subject was instructed to hold the STJN position while a ruler was placed alongside the medial aspect of the foot and the navicular tuberosity position was noted. The subject then assumed relaxed standing and the difference between navicular tuberosity positions on the ruler was recorded to the nearest millimeter. The ND test was repeated on the opposite limb, measured and recorded to the nearest millimeter.

Plantar flexor endurance

Plantar flexor endurance (PFE) was measured using the standing heel-rise test with slight modification based on differences between previous studies and available resources.[20,45-48] The standing heel-rise test measures endurance of the plantar flexor muscle group by determining the number of repetitions performed at a rate of 1 heel-rise every two seconds. With the subject standing barefoot and the knee and lower leg fully exposed, the subject was positioned arms length from a wall as determined by placing their hands at shoulder level, elbows fully extended, forearms pronated, wrists in neutral, fingers fully extended and only their finger tips touching the wall. The subject assumed single leg stance and was asked to perform a single heel rise. During this time the examiner ensured the subject could maintain balance without altering position, and placed two parallel uprights so that the dorsal aspect of the foot contacted a 0.5 mm piece of nylon string just distal to the anterior tibia.[45] The subject was instructed to use their fingertips for balance while keeping the upper extremities in the starting test position.[47,48] The subject was advised to keep the knee fully extended during testing and to contact the string with each heel-rise at a rate of one heel-rise every two seconds as determined by a metronome set at a cadence of 60 beats per minutes. The subject performed three to five practice repetitions to ensure correct performance of the test and was allowed to rest 60 seconds before beginning the test. The test was terminated when one of the following occurred: 1) knee flexion, 2) elbow or wrist flexion three times, 3) failure to contact the string for three consecutive repetitions, or 4) inability to continue due to fatigue. The number of heel-rise repetitions was recorded by the tester and the subject was allowed to rest for 60 seconds before testing the opposite leg. A value of 25 repetitions is considered normal for males and females based on previous work aimed at determining a reference standard.[46] The current study grouped subjects categorically based on a normal (≥25 heel-rise repetitions) or below normal (<25 heel-rise repetitions) PFE test result.

A pilot study to determine the intratester reliability of the PFE test was performed prior to data collection. Twenty-six subjects were recruited from the general student population at a participating university and measured on two separate occasions using the dominant leg. The intraclass correlation coefficient (ICC 3,1) and 95% confidence interval reliability values for the PFE test was 0.75 (0.52, 0.88; $p < 0.0001$). Ross et al measured test-retest reliability of the PFE test and reported an intraclass correlation coefficient of 0.96.[45] Although intratester reliability of the ND test was not assessed in this study, the researcher (MFR) who performed the ND measurement in the main cohort study, previously conducted a reliability study and reported intraclass correlation coefficient (ICC 3,1) values for right ND (ICC = 0.90), left ND (ICC = 0.78) and combined ND (ICC = 0.84) measures in a prior study.[4] Using the reliability data for the ND test the standard error of measurement (SEM) was calculated to be 1.2 mm.

Preseason Questionnaire

Subjects were asked to complete a 10 minute, preseason questionnaire that asked them to report their gender, age, ERLP history for the previous month and year, and current use of foot orthoses.

Exercise-related leg pain

Exercise-related leg pain (ERLP) is operationally defined as pain located in the anterior, medial, posterior, or lateral leg not associated with a traumatic injury.[8] Nirschl pain phase scores and visual analogue scores (VAS) were recorded in subjects having a history of ERLP and in-season occurrence of ERLP. The Nirschl pain phase scale is a seven-phase scale for overuse injuries ranging from transient pain that resolves within 24 hours to consistent pain that disrupts sleep and intensifies with activity.[33] Subjects with a Nirschl pain phase score of 4 or greater – described as pain resulting in alteration of performance – were subcategorized as having interfering ERLP.[33] The visual analog scale is an 11 point scale with zero equal to no pain and 10 equal to the worst imaginable pain. Subjects were also subcategorized into medial, lateral or posterior groups based on the location of their ERLP.

At the end of the competitive cross-country season, the subjects received an email with a web address and request to complete an online postseason questionnaire. Subjects completing the survey were assigned to one of two groups based on the occurrence of ERLP during the 2009 cross-country season. Location and severity of pain were recorded and pain severity was quantified using Nirschl pain phase scores and VAS ratings as in the preseason questionnaire.

Data Analysis

Mean differences between subjects with and without in-season occurrence of ERLP were determined using independent, 2-tailed t-tests for continuous variables (ND, PFE, BMI, age). Crude odds ratios with 95% confidence intervals were initially calculated for ND (>10/≤10 mm), PFE (<25/≥25 repetitions), and other factors (prior ERLP injury, gender), and in-season occurrence of ERLP or in-season occurrence of medial ERLP. Multivariate logistic regression analysis was used to examine relationships between all measured variables and potential confounders and the in-season occurrence of ERLP and in-season occurrence of medial ERLP. All statistical tests were set at the 0.05 level of significance. All data were recorded and analyzed using SPSS statistical software (version 18.0, Chicago, IL).

RESULTS

While 77 (44 males, 33 females) of 100 (56 males, 44 females) rostered cross-country athletes from four universities and one college consented to participate in this study prior to the 2009 cross-country season, only 59 (31 males, 28 females) of the original subjects completed the end of season questionnaire. The eighteen subjects (13 males, 5 females) who failed to complete the end of season questionnaire were not included in the final data analysis.

There were no significant differences in descriptive categorical variables between the 18 subjects who dropped out and the 59 subjects completing the study (TABLE 1). Subjects denying a history of ERLP in the previous month (29.4%) or year (28.6%) had a tendency that approached statistical significance to drop out compared to subjects with a history of ERLP in the previous month (11.5%, $p = 0.08$) or year (21.4%, $p = 0.51$), respectively. The tendency to drop out was not different in subjects denying a history of ERLP in the last year (28.6%) compared to subjects with a previous year history of ERLP (21.4%, $p = 0.51$). Gender also approached significance with males nearly twice as likely to drop out (29.5%) than females (15.2%, $p = 0.14$). There were no significant differences for continuous independent variables (ND, PFE, Age, and BMI) between study participants and those who did not complete the study.

The overall in-season occurrence of ERLP was 44.1% ($n = 26$), with an equal number of male and female subjects reporting ERLP during the season. There were no significant differences in gender, age, or BMI between those with and without previous history of ERLP or in-season occurrence of ERLP. BMI < or > 18.5 kg/m^2 and gender were not significantly different between subjects who did or did not experience ERLP or medial ERLP (TABLE 2) during the season. A greater percentage of subjects with a history of ERLP in the month prior to the study localized their pain to the medial leg, but location was not significant for previous month history of ERLP or in-season occurrence of ERLP. On average, subjects ($N = 59$) performed 26.6 ± 11.5 heel-rise repetitions on the right and 22.9 ± 8.5 heel-rise repetitions on the left during the PFE test (TABLE 3). There was no difference between groups based on the occurrence of in-season ERLP for mean PFE (TABLE 3) or for those scoring < 25 repetitions on the PFE test (TABLE 2) regardless of pain location. Mean PFE (TABLE 3) or performance of < 25 repetitions on the PFE test (TABLE 2) also did not differ between groups based on the in-season occurrence of medial ERLP. Females were over 3 times more likely than males to perform less than 25 repetitions during PFE testing ($p = 0.045$).

Means and standard deviations for all subjects ($N = 59$) are provided for right ND (8.5 ± 4.1) and left ND (8.7 ± 4.3) measures in TABLE 3. A comparison of subjects by in-season occurrence of ERLP did not differ significantly for mean ND (TABLE 3) or ND > 10 mm (TABLE 2). No significant differences were

Table 1. *Characteristics of subjects by study status.*

	Total (n=77) N (%)	Responder (n=59) N (%)	Dropout (n=18) N (%)	p-value†
BMI < 18.5 kg/m^2	10 (13.0)	8 (13.6)	2 (11.1)	0.79
Gender (female)	33 (43.0)	28 (47.5)	5 (27.8)	0.14
ND > 10 mm	33 (42.9)	26 (44.1)	7 (38.9)	0.70
PFE < 25	53 (68.8)	41 (69.5)	12 (66.7)	0.82
ERLP History (month)	26 (33.8)	23 (39.0)	3 (16.7)	0.08
ERLP History (year)	56 (72.7)	44 (74.6)	12 (66.7)	0.51

BMI= body mass index; ND= navicular drop; PFE= plantar flexion endurance; ERLP= exercise-related leg pain
†Chi-square test

Table 2. *Crude odds ratios for in-season occurrence of ERLP and medial ERLP by baseline characteristics.*

Factor (category)	ERLP *N*	(%)	Odds ratio (95% CI)	Medial ERLP *N*	(%)	Odds ratio (95% CI)
BMI						
< 18.5 (underweight)	8	(62.5)	2.4 (0.5 – 11.1)	8	(25.0)	1.6 (0.3 – 9.0)
18.5-24.9 (normal)	51	(41.2)	1.0	51	(17.6)	1.0
Gender						
Female	28	(46.4)	1.2 (0.4 – 3.4)	28	(25.0)	2.3 (0.6 – 8.7)
Male	31	(41.9)	1.0	31	(12.9)	1.0
ERLP History (year)						
Yes	44	(56.8)	18.4 (2.2 – 152.7)†	44	(22.7)	4.1 (0.5 – 35.3)
No	15	(0.07)	1.0	15	(6.7)	1.0
ERLP History (month)						
Yes	23	(73.9)	8.5 (2.6 – 28.2)‡	23	(34.8)	5.9 (1.4 – 25.3)§
No	36	(0.3)	1.0	36	(8.3)	1.0
Right ND (mm)						
> 10 (hyperpronation)	19	(42.1)	0.9 (0.3 – 2.7)	19	(31.6)	3.2 (0.8 – 12.4)
≤ 10	40	(45.0)	1.0	40	(12.5)	1.0
Left ND (mm)						
> 10 (hyperpronation)	24	(45.8)	1.1 (0.4 – 3.2)	24	(33.3)	5.3 (1.2 – 22.9)**
≤ 10	35	(42.9)	1.0	35	(8.6)	1.0
Right or Left ND (mm)						
> 10 (hyperpronation)	26	(42.3)	0.9 (0.3 – 2.5)	26	(30.8)	4.4 (1.0 – 18.9)††
≤ 10	33	(45.5)	1.0	33	(9.1)	1.0
Right PFE (reps)						
< 25 (below normal)	26	(42.3)	0.9 (0.3 – 2.5)	26	(23.1)	1.7 (0.5 – 6.3)
≥ 25 (normal)	33	(45.5)	1.0	33	(15.2)	1.0
Left PFE (reps)						
< 25 (below normal)	25	(60.0)	0.9 (0.3 – 2.5)	35	(20.0)	1.3 (0.3 – 4.9)
≥ 25 (normal)	24	(45.8)	1.0	24	(16.7)	1.0
Right or Left PFE (reps)						
< 25 (below normal)	41	(43.9)	1.0 (0.3 – 3.0)	41	(19.5)	1.2 (0.3 – 5.2)
≥ 25 (normal)	18	(44.4)	1.0	18	(16.7)	1.0

ERLP= exercise-related leg pain; BMI= body mass index; ND= navicular drop; PFE= plantar flexor endurance; CI= confidence interval.
†P=0.001
‡P<0.0001
§P=0.01
**P=0.02
††P=0.03

Table 3. *ND and PFE by in-season occurrence of ERLP and medial ERLP.*

Group	ND Measurement (mean ± SD), mm		PFE Measurement (mean ± SD), reps	
	Right ND	Left ND	Right PFE	Left PFE
All (N=59)	8.5 ± 4.1	8.7 ± 4.3	26.6 ± 11.5	22.9 ± 8.5
ERLP (N=26)	8.5 ± 4.3	9.0 ± 4.7	27.2 ± 12.5	22.9 ± 8.8
No ERLP (N=33)	8.6 ± 4.1	8.5 ± 4.0	26.2 ± 10.9	22.9 ± 8.4
Medial ERLP (N=11)	10.6 ± 4.2	11.6 ± 4.4†	26.6 ± 14.4	22.5 ± 8.9
No Medial ERLP (N=48)	8.0 ± 4.0	8.0 ± 4.1†	26.7 ± 10.9	22.9 ± 8.5

ND= navicular drop; PFE= plantar flexor endurance; ERLP= exercise-related leg pain; SD= standard deviation.
†Significant mean differences (P=0.01)

Table 4. *Adjusted odds ratios for potential risk factors of in-season ERLP and in-season medial ERLP†*

Variables in the equation	In-Season ERLP		In-Season Medial ERLP	
	Odds ratio	(95% CI)	Odds ratio	(95% CI)
ND > 10 mm	0.7	(0.2 – 2.6)	6.6‡	(1.2 – 38.0)
ERLP History (month)	12.3§	(3.1 – 48.9)	10.3**	(1.7 – 61.9)
Gender (female)	1.1	(0.3 – 4.2)	3.6	(0.6 – 21.8)

ERLP= exercise-related leg pain; ND= navicular drop; CI= confidence interval.
†Adjusted for categorical body mass index, age, gender, and plantar flexor endurance (<25 repetitions)
‡P =0.03
§P <0.0001
**P =0.01

identified between females and males for ND > 10 mm. Subjects reporting in-season occurrence of medial leg ERLP had a significantly higher mean ND (TABLE 3) and ND >10 mm (TABLE 2) than subjects not reporting in-season occurrence of medial leg ERLP. Left leg mean ND was greater in subjects with in-season occurrence of medial ERLP (11.6 ± 4.4) compared to subjects without in-season occurrence of medial ERLP (8.0 ± 4.1, p = 0.01). Although the difference in mean right leg ND was higher among subjects who reported in-season occurrence of medial ERLP than subjects without medial ERLP, only a non-significant trend was found (10.6 ± 4.2 vs. 8.0 ± 4.0, p = 0.06). Subjects with ND measures >10 mm on either leg had a 4 times (OR = 4.4; 95% CI = 1.0–18.9, p = 0.03) greater odds of developing in-season occurrence of medial ERLP (TABLE 2).

When adjusting for age, gender, BMI and PFE (< 25 repetitions), only a previous month history of ERLP (OR = 12.3, 95% CI = 3.1-48.9) was associated with increased likelihood of ERLP during the season in the final multivariate logistic model (TABLE 4). Both ND >10 mm (OR = 6.6, 95% CI = 1.2-38.0) and previous month history of ERLP (OR = 10.3, 95%CI = 1.7-61.9) were associated with occurrence of medial ERLP during the season in the final multivariate logistic model after adjusting for age, gender, BMI and PFE (< 25 repetitions) (TABLE 4).

DISCUSSION

A number of potential risk factors for the development of overuse injuries in distance runners have been identified in the literature. Retrospective and case-control studies have examined differences between subjects with and without the overuse injury of interest, but they have been unable to account for the sequencing of events. The intent of this research was to measure a number of potential risk factors prospectively and determine their association with developing ERLP in a group of healthy collegiate runners during the 2009 competitive XC season. Risk factors identified as being significantly associated with overuse injury in runners could then be studied using randomized, controlled designs to examine prevention and treatment methods.

The overall occurrence of ERLP in this sample of 59 cross-country runners was 44.1%, with an equal number of male (n = 13) and female (n = 13) athletes reporting ERLP. Previous prospective studies have reported in-season occurrence of ERLP in athletes ranging between 26% and 48%.[4,5,8,49] Medial tibial stress syndrome has been described as exercise-induced, localized pain occurring along the distal two-thirds of the posteromedial tibia.[29,50] Prospective studies reporting incidence rates for medial tibial stress syndrome have reported values between 7.5% to 19.8%[11,14,24] Roughly 18% of runners in this study described season ERLP localized to the medial lower leg, although without clinical examination and imaging, other pathologies cannot be ruled out.

The results of this study are consistent with previous studies demonstrating a significant relationship between medial leg pain in runners and excessive pronation.[7,8,12,14,25,27,35] Bandholm et al[12] retrospectively measured ND in their study and found significantly greater pronation in subjects with MTSS (7.7 +/- 3.1) compared to controls (5.0 +/- 2.2, p = .046). Reinking et al[8] reported the odds were three times greater for developing ERLP during the competitive season in a group of female collegiate athletes with a ND ≥ 10 mm compared to female collegiate athletes with a ND < 10 mm. Although the results were based on ERLP regardless of location, 75% of subjects localized their pain to the medial leg. Bennett et al[14] showed ND and gender correctly predicted the occurrence of MTSS 76% of the time in a group of 125 high school cross-country athletes, with female subjects having larger ND more likely to develop MTSS. These data are consistent with biomechanical and anatomical studies that support the adverse effects of excessive pronation on bony and soft tissues located along the posteromedial tibia.[13,15,16,21,22,39,51]

Other authors who used ND to measure pronation did not find a significant difference in subjects with and without leg pain.[4,5,11,24] In two separate studies, Reinking et al[4,5] did not find a difference in ND data based on the in-season occurrence of ERLP. Most subjects in these studies reported bilateral medial leg pain, yet comparison of ND measures did not account for the location of ERLP; therefore their findings are consistent with the current study when considering all leg pain. Two prospective studies measured ND in a group of athletes and failed to find a significant difference between healthy subjects and subjects developing MTSS during the season.[11,24] Hubbard et al[11] studied a sample of 146 collegiate athletes from six different sports: cross-country, track & field, tennis, soccer, volleyball, and cheerleading. While the majority of athletes developing MTSS (n = 29) participated in cross-country (n = 14) and track & field (n = 9), the potential influence of different sports on the results cannot be ignored. Plisky et al[24] excluded subjects with symptoms of MTSS from their study of 105 high school cross-country runners, but did not report the number of subjects excluded based on this criterion. Because prior studies have shown a relationship between MTSS and ND,[12,14] it is possible the exclusion of subjects with symptoms of MTSS in the Plisky et al[24] study also decreased the number of subjects likely to demonstrate excessive pronation. Differentiating symptoms from injury and comparing ND measures in symptomatic subjects to asymptomatic subjects may provide more insight into potential differences between groups. This study did not find a significant relationship between pronation and in-season occurrence of ERLP localized to the lateral or posterior leg, supporting the influence of excessive pronation on the occurrence of medial leg pain. Failing to find a significant relationship between the in-season occurrence of ERLP and pronation – regardless of location - is likely due to the influence of other intrinsic or extrinsic factors in the development of lateral and posterior leg pain.

Decreased performance and imbalance of lower extremity muscles have been suggested as potential risk factors for overuse injuries in runners.[20,52] Fatigue of the ankle plantarflexors has been identified as a possible etiological factor in the development of overuse injuries involving the lower leg.[20,52] In a study by Milgrom et al,[52] in vivo tibial tension strains and peak gastrocnemius torque were measured before and after a 2 km run and 30 km march. Peak isometric gastrocnemius torque decreased and medial, mid-tibial tension strains increased significantly as a result of the prescribed activity. Though the authors hypothesized that muscle fatigue resulting in increased tibial tension may lead to overuse injury, they did not find a significant difference in ground reaction forces post-run or post-march. Further, most tests demonstrated decreased peak vertical forces. While it seems likely that muscle fatigue could result in decreased attenuation of ground reaction forces, it is also possible compensatory strategies occur to counteract the effects of muscle fatigue. Future studies need to determine if differences in the degree of muscle fatigue are related to injury as muscle fatigue may result in increases in stress thereby exposing those with structural and biomechanical faults to injury. The degree and timing of fatigue is likely a reflection of conditioning and not a predilection for injury.

Madeley et al[20] compared isotonic plantar flexor endurance among a group of symptomatic athletes with medial tibial stress syndrome (MTSS) to a group of matched controls. MTSS was defined as exercise related leg pain occurring in the last week and reproduced with palpation of the postero-medial tibial border. They observed that athletes with MTSS performed significantly fewer heel rise repetitions on average compared to a group of matched controls. Subjects in Madeley's study reported a chronic history of MTSS (median 15 weeks) with 77% of subjects describing pain resulting in a decrease in everyday activities. The authors acknowledged that reduced activity resulting from pain over an extended period is likely to result in decreased PFE in subjects with MTSS. Therefore, it is possible that reduced PFE was a consequence rather than a risk factor for chronic overuse lower leg pain in athletes. The current study was the first to prospectively measure PFE in non-injured runners prior to their competitive season and found no significant differences in mean heel-rise repetitions between runners developing in-season ERLP and runners remaining free of leg pain. Similar findings were found for medially located in-season occurrence of ERLP, suggesting that reduced PFE is not associated with the increased likelihood of MTSS.

Lunsford et al suggested using twenty-five repetitions as a reference standard for isotonic plantar flexor endurance at a rate of one heel rise every two seconds.[46] In this study, the subjects demonstrated a higher mean PFE on the right leg (26.6 $\pm$ 11.5 repetitions) and lower mean PFE on the left leg (22.9 $\pm$ 8.5 repetitions) compared to the reference standard, although the normal value of 25 repetitions fell within one standard deviation of the mean. Although the subjects in this study were healthy collegiate runners, their mean PFE values are not greater than those reported in other studies using subjects who are older, injured or are not collegiate athletes.[20,45,46] The current study was the first to examine and report risk of developing in-season occurrence of ERLP based on exposure by using Lunsford's recommended 25 repetitions as a cut-point. Subjects who performed less than 25 repetitions did not significantly increase the risk of incurring in-season ERLP in this cohort of collegiate XC runners regardless of leg pain location. Performing less than 25 heel-rise repetitions, however, was significantly related to gender, with 82.1% of females testing below the reference standard. While prior studies have reported female gender as a significant factor for overuse injury, the authors of the current study are unaware of any other studies reporting significant differences in PFE between male and female subjects.[3,7,14,24,40]

These data revealed a significant relationship between in-season occurrence of ERLP and history of ERLP during the past month or year. History of previous injury has been reported in numerous studies as a significant risk factor for recurring leg pain in runners.[4,5,8,11,41,49] As injury is often times defined as an inability to perform normal activities or time loss from activity, the authors further classified leg pain using the Nirschl pain phase scale for overuse injuries.[32,33] Athletes describing their leg pain as four or greater on the Nirschl phase pain phase scale were considered to have interfering leg pain because their pain resulted in alteration of athletic or daily activities. A significant relationship was found between runners with a history of ERLP and in-season occurrence of interfering ERLP. An important observation was that 100% of runners denying a history of ERLP over the last year remained painfree during the course of the competitive season, and 75% of runners with a history of ERLP in the previous month developed in-season occurrence of interfering ERLP. Thus, identifying runners with a history of interfering ERLP prior to the competitive season may allow for earlier prevention and intervention strategies.

Several limitations of study are noted. An a priori power analysis determined that a sample size of 262 subjects was needed to detect a statistically significant association between navicular drop and ERLP. However, the final sample size of this study was 59 subjects completing all measures. Despite the small sample size the strength of the relationship between medial ERLP and pronation likely resulted in the significant findings. An underpowered study increases the likelihood of committing a Type II error and not finding a significant difference when one truly exists. Future studies should include larger sample sizes to improve the strength of the study and reduce the risk of committing a Type II error.

Exercise-related leg pain is a regional description of pain and as such does not differentiate between overuse pathologies commonly associated with endurance activities. Identifying risk factors for specific overuse injuries – such as MTSS - may allow for more direct intervention. On the other hand, interventions are directed at structural and biomechanical impairments identified during the examination process, and not at a specific diagnosis. A dynamic, recursive model for sports injury takes into consideration the interaction of modifiable and non-modifiable risk factors during repeated exposure to environmental stress.

Another limitation of this study involves the timing of athlete's reporting ERLP. Subjects were asked to complete a follow-up survey at the completion of their season regardless of when they experienced ERLP. Athletes experiencing ERLP early in the season may have a more difficult time recalling details regarding location and intensity of their pain. Having the athletes complete a questionnaire during the season at frequent intervals likely would have allowed for increased accuracy in the identification of the onset and severity of ERLP. Differences in training and the number of exposures each subject experienced during the season further limited the study findings. Tracking exposures and mileage would provide further detail regarding the influence of training volume on the development of overuse injury. Finally, the subjects in this study were on average 19.3 years of age and rostered on a collegiate cross-country team during the 2009 season. Generalizing the results of the current study to the larger running community is likely limited due to the unique training and fitness characteristics of this somewhat unique population.

In conclusion, isotonic ankle plantar flexor endurance and excessive pronation were not risk factors for in-season occurring ERLP in this group of collegiate cross-country runners. When accounting for the location of leg pain, excessive pronation was found to be a significant risk factor for in-season occurrence of ERLP localized to the medial leg. A history of ERLP was associated with increased risk of developing ERLP and interfering ERLP during the competitive season. Excessive pronation, i.e., navicular drop greater than 10 mm, and a history of ERLP were found to be significantly associated with in-season occurrence of ERLP localized to the medial leg. Future studies examining the effect of strength and pronation on ERLP should include a larger sample of collegiate cross-country runners as well as in other competitive and recreational running populations.

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